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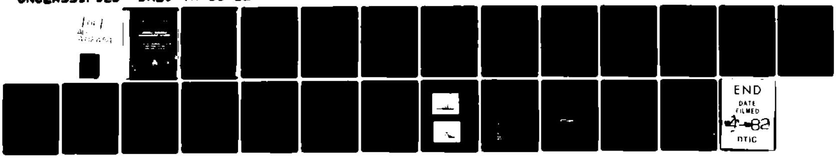

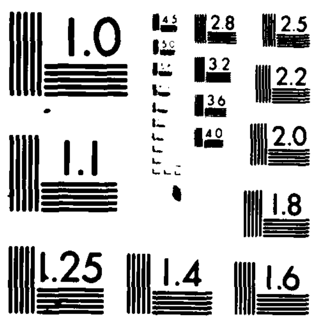
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THE DESIGN AND PERFORMANCE OF A BI-PHASE CODED SPREAD SPECTRUM RADAR SIGNAL GENERATOR

by

J.J. Renaud and L.G. Rowlandson

RESM Section

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ABSTRACT

A bi-phased coded spread spectrum radar signal generator was developed to be used in testing the effectiveness of ESM receivers.

The generator permits code sequences to be selected to a maximum value of 10, which in turn sets the microwave pulse width from 10 to a minimum of 2 μsec.

The PRF of microwave pulses is nominally set at 1 KHz and carrier frequency is selectable in 100 MHz increments from 8 - 12.4 GHz.

RÉSUMÉ

Un générateur de signaux de radars à spectre diversité par codage biphasé a été développé pour vérifier l'efficacité de certains types de récepteurs E.S.M.

Le générateur permet le choix de séquences codeés de longueur maximum de 10, qui en retour, règle la longueur de la pulsation micro-onde à un minimum de 2 μsec.

La fréquence entre pulsations micro-ondes est bloqueé à 1 KHz tandis que la fréquence porteuse est sélective de 8.0 à 12.4 GHz par écart de 100 MHz.

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1.0 INTRODUCTION

A bi-phase coded, spread spectrum radar signal generator was developed to support ESM research in the detection and analysis of these types of complex signals.

The fundamental purpose in using bi-phase coding is to modulate a microwave carrier signal using a discrete code which will permit the radar designer to achieve increased system resolving capability both in range and velocity. Furthermore, since the radar receiver is matched to the particular code the radar system is less vulnerable to interfering signals that do not have the same properties as the coded waveform (Ref. 1).

By using such coding techniques the energy of a fundamental microwave carrier is spread over a wide frequency range and the peak power in a pulse can be reduced which in combination makes the radar signal much more difficult to detect.

Barker code sequences have been adopted by radar designers to achieve particular range and velocity resolution where the phase of the RF carrier in a pulse is reversed depending upon the binary code sequence. The effect is to produce a frequency spectrum consisting of discrete frequency components which may encompass a frequency range of several hundred megahertz.

2.0 THE BI-PHASE CODED RADAR SIGNAL GENERATOR

Figure 1 shows a carrier signal being phase coded under the control of a binary code sequence. Each time interval, δ, in the code sequence corresponds to one cycle of the carrier signal and the phase of the carrier signal is reversed whenever the code changes from a maximum to minimum value. In practice the maximum code value would correspond to "1" and the minimum value to "0" in the Barker code sequence.

Referring to Figure 2, the basic clock signal is derived from a crystal controlled oscillator which is imbedded in a commercial Comb Generator SCG 100. The 100 MHz CW clock is modulated by a step recovery diode (SRD) which produces a comb of frequencies covering the band 0.1 to 18 GHz with 100 MHz spacing between frequency components.

A narrow band tunable YIG filter is used to select a particular frequency in the comb spectra extending from 8 - 12.4 GHz, for example, 8.1 or 8.2, and so on. The selected frequency is coherent with the fundametnal clock signal as are all other microwave frequency components.

The selected microwave frequency carrier is then modulated by a PIN diode using pulses derived from electronic circuits, described in later Sections, to provide a series of microwave pulses having a particular width and repetition period (PRI).

The pulsed signals are fed to a bi-phase modulator where the phase of the microwave carrier signal can be switched by 180°, on command, from a

video pulse sequence. The video pulse sequence is selected according to the desired Barker code.

The video pulse interval is synchronized with the master 100 MHz clock such that the interval between microwave pulses is a discrete number of clock cycles. Therefore, when a particular modulation is applied to one RF pulse this can be repeated in precise time correlation for all pulses. In this way the frequency spectrum generated can be maintained phase coherent pulse to pulse, within the stability of the master clock.

3.0 DESIGN OF THE ELECTRONICS SUBSYSTEM

With reference to Figure 3, one of the functions of the Electronic Subsystem is to provide video pulses to the PIN modulator which will set the pulse width and repetition period of the coded RF signal. These pulses are generated in synchronism with the 100 MHz clock signal such that the RF signal is replicated in phase on a pulse to pulse basis. This implies that the PRI is as stable as the master clock signal. It will also be shown that in this first design the width of the pulses is a function of the code selected by the operator.

The Electronic Subsystem also generates the video modulating waveform to the bi-phase modulator, where the phase of each interval in the sequence corresponds to the selected binary code pattern, as shown in Figure 1.

Detailed information on the design and function of each of these elements will now be presented.

3.1 Pulse Repetition Interval Circuits

Referring to Figure 4, integrated circuits 1 through 7, are used to set the pulse repetition interval of the spread spectrum microwave signal.

A sample of the 100 MHz master clock signal is applied to an Integrated Circuit, IC_1, to produce a square wave, ECL level, clock signal. IC_2 is a buffer/driver used to distribute this clock signal. IC's 3 through 7 are decade counters which divide the 100 MHz square wave clock signal by 10^5 to produce pulses separated by 1 ms interval.

3.2 Pulse Width Circuit

Referring to Figure 5, IC_8, which is driven from the 100 MHz clock buffer IC_2, is a programmable decade counter. The program inputs P_0 through P_3 set a binary number. The division accomplished in this IC changes the output frequency, f_0, according to,

$$f_0 = \frac{100 \text{ MHz}}{10 - \text{binary number}} \tag{1}$$

For example, if P_0 through P_3 is set to [0000], or zero, f_0 is equal to 10 MHz with a period of 100 ns; if set to [1000], or 8, f_0 is 50 MHz with a period of 20 ns.

The output of IC_8 is then fed to IC_{10} and IC_{11} which together divide the frequency by 100, that is, multiply the period by 100.

For an IC_8 program [0000] the frequency from IC_{11} is then 0.1 MHz with a period of 10 μsec; if [1000] the frequency from IC_{11} is then 0.1 MHz with a period of 2 μsec.

The outputs from IC_7 (PRI) and IC_{11} (PW) are applied through IC_9 inverters to an S.R. flip-flop IC_{12}. The leading edge of each PRI pulse sets the flip-flop and the PW counters IC_{10} and IC_{11}. The output of the PW counters resets the flip-flop to produce a video pulse train which has the PRI set by the PRI circuit of 3.1 and a PW set by multiplying the period of f_0 by 100. For example, as shown above, for code [1000], f_0 is 50 MHz of period 20 ns so the final overall pulse width will be 2 μs.

3.3 Shift Registers

Referring to Figure 6, the signal from the flip-flop, IC_{12}, is fed to shift registers, IC's 3 - 15.

The inputs to these shift registers, D_0 through D_9 are programmable such that "0" means no phase shift and "1" means 180° phase with the 100 MHz clock signal from IC_2 used to shift out the data.

All shift registers are controlled from IC_{12} which contains the PRI and PW control information. The shift registers are connected in a serial in/out data transfer with programmable inputs loaded in parallel. The output of the shift register IC_{15} is a serial data stream of level "0" or "1" depending on the code sequence loaded through D_0 - D_9.

3.4 Summary of Video Phase-Shifting Code

The circuits described above permit one to select a code containing a sequence "1" and "0" pulses to a maximum of 10 using the switches D_0 - D_9. Each pulse is 10 ns in width.

The pulse width, is determined by the binary number set on the four "P" switches.

For example, suppose we select a code 010 by setting 0 on D_0, 1 on D_1 and 0 on D_3. Using a binary number 7 on the P switches, that is 0111, the output frequency given by equation (1) is then 100/3 MHz with a period of 20 ns. This 30 ns time period is used to control the shifting out of the 010 code which in this case is 3 x 10 ns or 30 ns in length.

Since the radar pulse width generated by the circuit described in 3.2 is 100 times the period of f_0, the code 010 will repeat 100 times within a pulse width of 3 μsec.

Therefore, in this generator, the code selected by the "D" switches defines the binary number set on the "P" switches such that the code repeats exactly 100 times in a pulse width. The binary number is then always set to 10 minus the code length which in the case above is 10 - 3, or 7, where 3 code

pulses are used.

The longest code length is generated by using all ten "D" switches to give an overall length of 100 ns. The "P" switches are set to 10 - 10, or 0, and the radar pulse width from section 3.2 is then 10 μsec and the code repeats 100 times within the pulse.

This design, which may appear rather constrained, was implemented using readily available components. Work is already underway on a new design which will permit one to select codes, pulse widths and PRF's with a great deal more flexibility.

For completeness, Figure 7 provides a master circuit schematic of the Electronic Subsystem.

4.0 EXPERIMENTAL RESULTS

The frequency spectrum of various biphase coded microwave pulses are shown in the following sequence of polaroid recordings.

The microwave carrier frequency was selected by the YIG to be 9.1 GHz with a pulse repetition period of 1 ms for all test conditions.

Figure 8 shows the frequency spectrum using code 010 (3 pulses). Referring to Section 3.3 and Figure 6, the program inputs are then 0 on D_0, 1 on D_1 and 0 on D_2. This code repeats for the duration of the pulse.

The binary number set on the P switches is then 10 - 3, or 7, which is 0111.

Referring to Section 3.2, the selection of 0111 (7) produces a pulse width of 3 μsec, or, 100 times the 3 pulse code interval.

The frequency spacing of spectral lines is equal to the reference frequency of 100 MHz divided by the number of pulses in the code, which, in this case is

$$\Delta f = 100 \text{ MHz}/3 = 33.3 \text{ MHz} \qquad (2)$$

Since we are dealing with a pulsed microwave carrier the frequency spectrum of each individual spectral line has a sin x/x spectrum, as shown in Figure 9.

Figure 10 shows the frequency spectrum for a code 1010 (4 pulses). Inputs D_0 through D_3 are then set to 1010 respectively and a binary number of 6 was set on P_0 through P_3 to produce a pulse width of 4 μsec.

There are two interesting effects shown on this record. First of all the carrier is suppressed. Secondly, the frequency spacing of the spectral lines from the carrier frequency is 50 MHz, whereas, one would expect it to be 100 MHz/4, or 25 MHz. In fact the code 1010 is a repetition of 10 which is the least element of the sequence. The spacing of frequency components then turns out to be 100 MHz/2 or 50 MHz, as shown.

One final example is shown on Figure 11, using the longest code we could generate, namely, 1101011000, which uses all D_0 through D_9 switches and generates a pulse width of 10 μsec by setting a binary number of zero on the P switches.

The spectral line separation is 100 MHz/10 or 10 MHz, as shown. The carrier component is partially suppressed but visible.

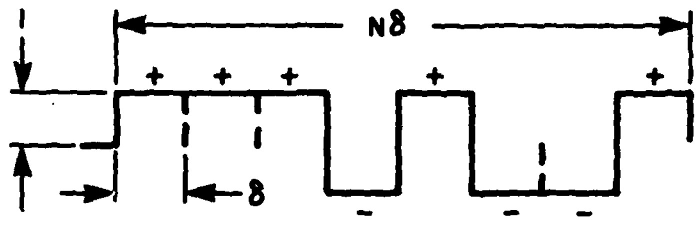
5.0 CONCLUSIONS

Following breadboard tests the Spread Spectrum Generator was configured for rack mounting and laboratory signal simulation use, as shown in Figure 12.

This first design was intended to gain experience in techniques used to generate biphase coded spread spectrum signals and to produce a unit which could be used to evaluate the effect of these signals on ESM receivers.

6.0 REFERENCES

1. Charles E. Cook & Marvin Bernfeld, "Radar Signals, An Introduction to Theory & Application", Academic Press, 1967.



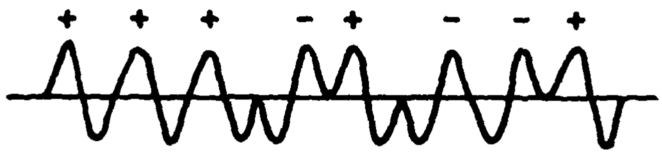


FIGURE 1 - BINARY CODED SIGNALS

A) VIDEO AMPLITUDE MODULATION
B) PHASE REVERSAL CW CODED SIGNAL

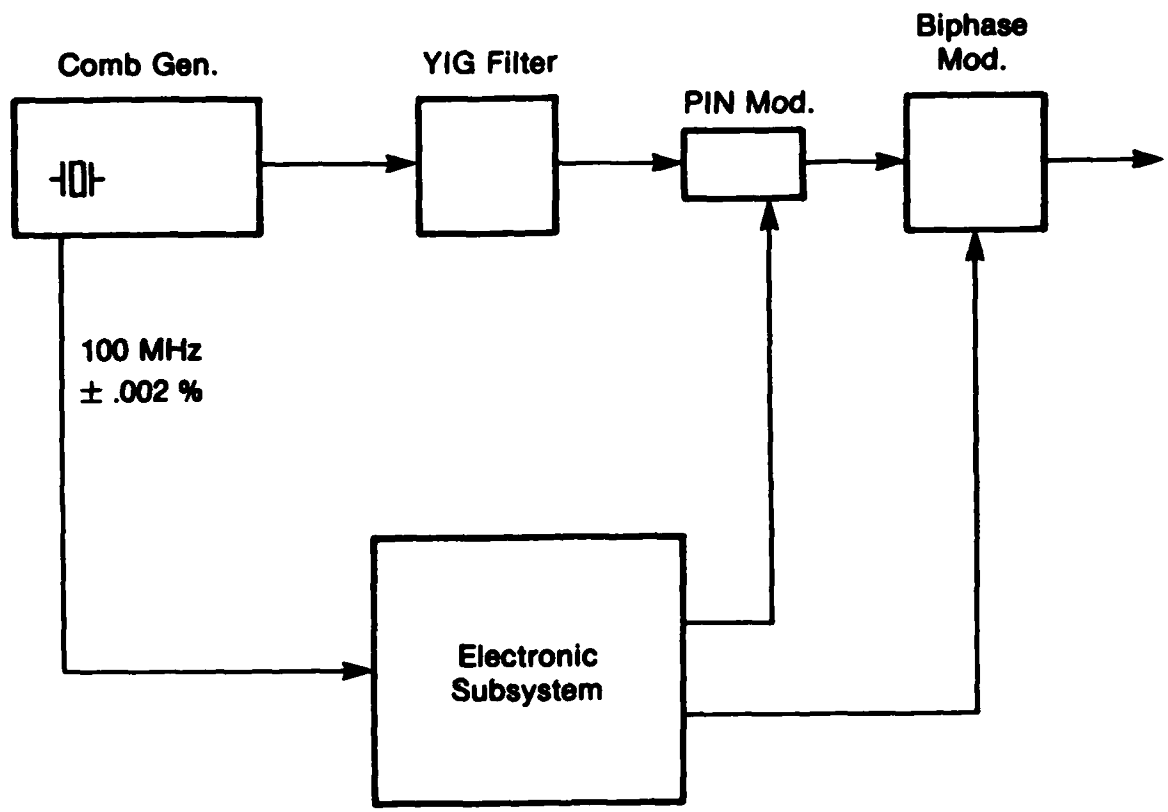


FIGURE 2 - BLOCK DIAGRAM OF RF SUBSYSTEM

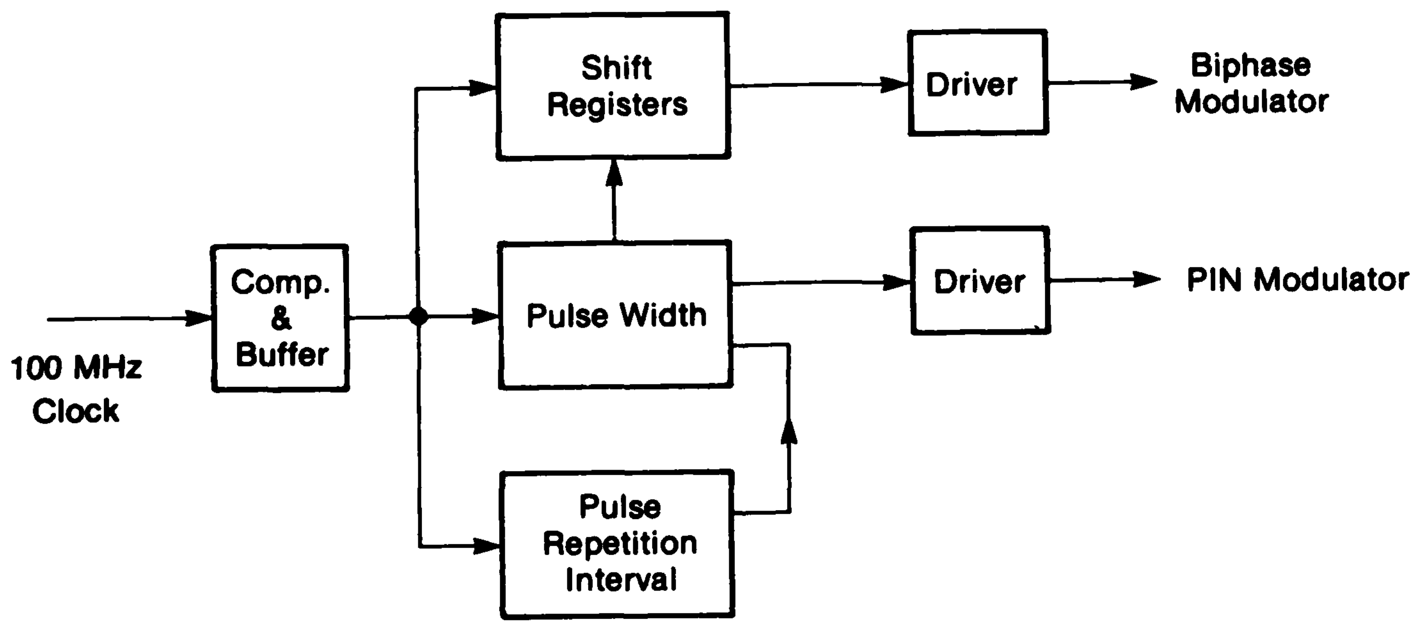


FIGURE 3 - SCHEMATIC OF VIDEO PULSE CIRCUITS

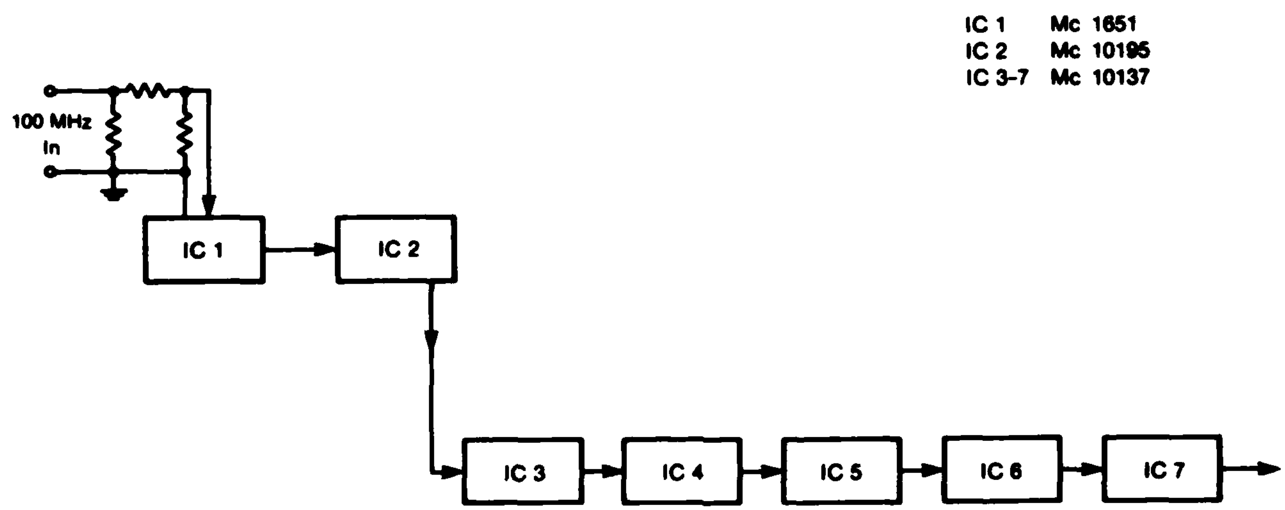


FIGURE 4 - PULSE REPETITION INTERVAL CIRCUIT

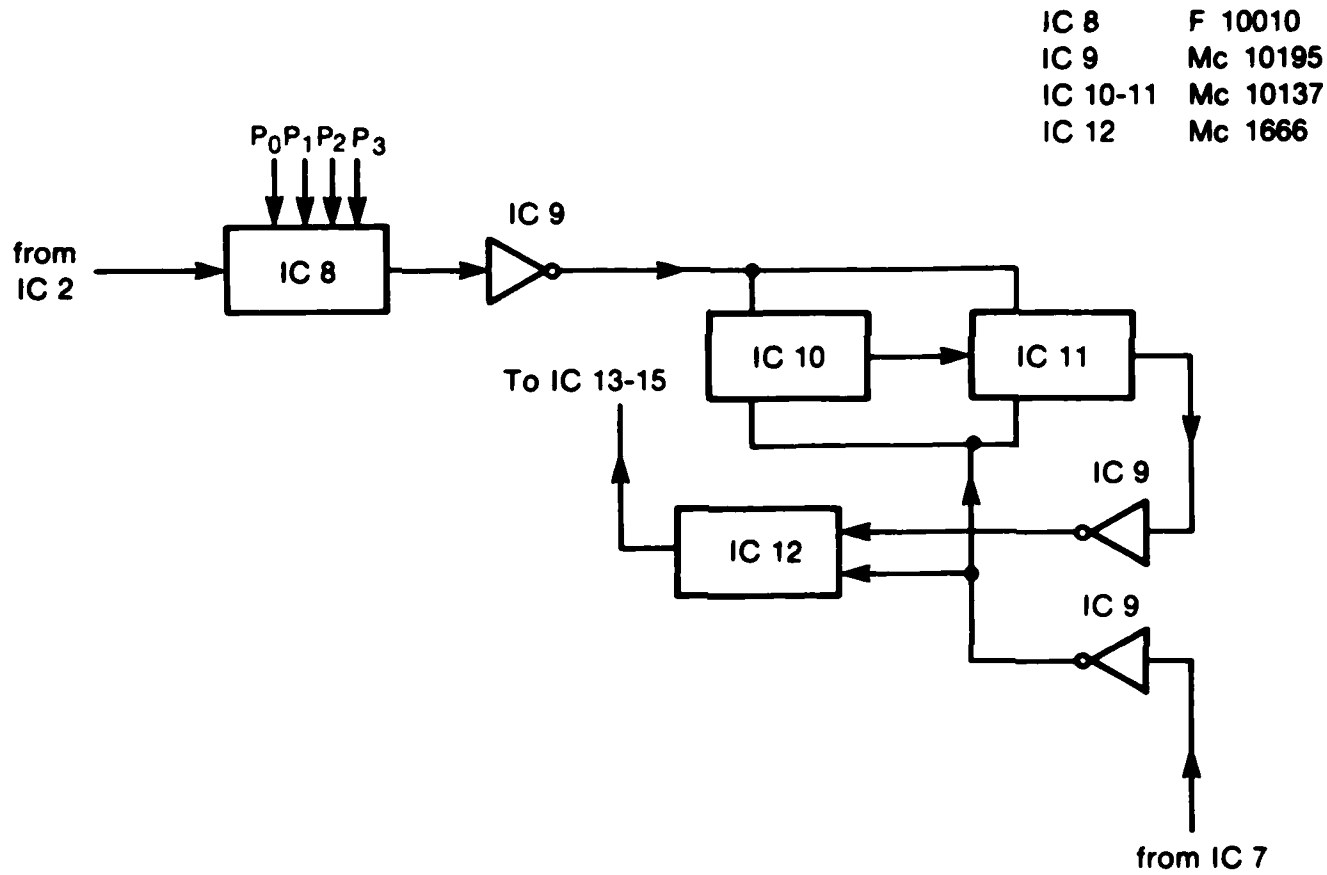


FIGURE 5 - PULSE WIDTH CIRCUIT

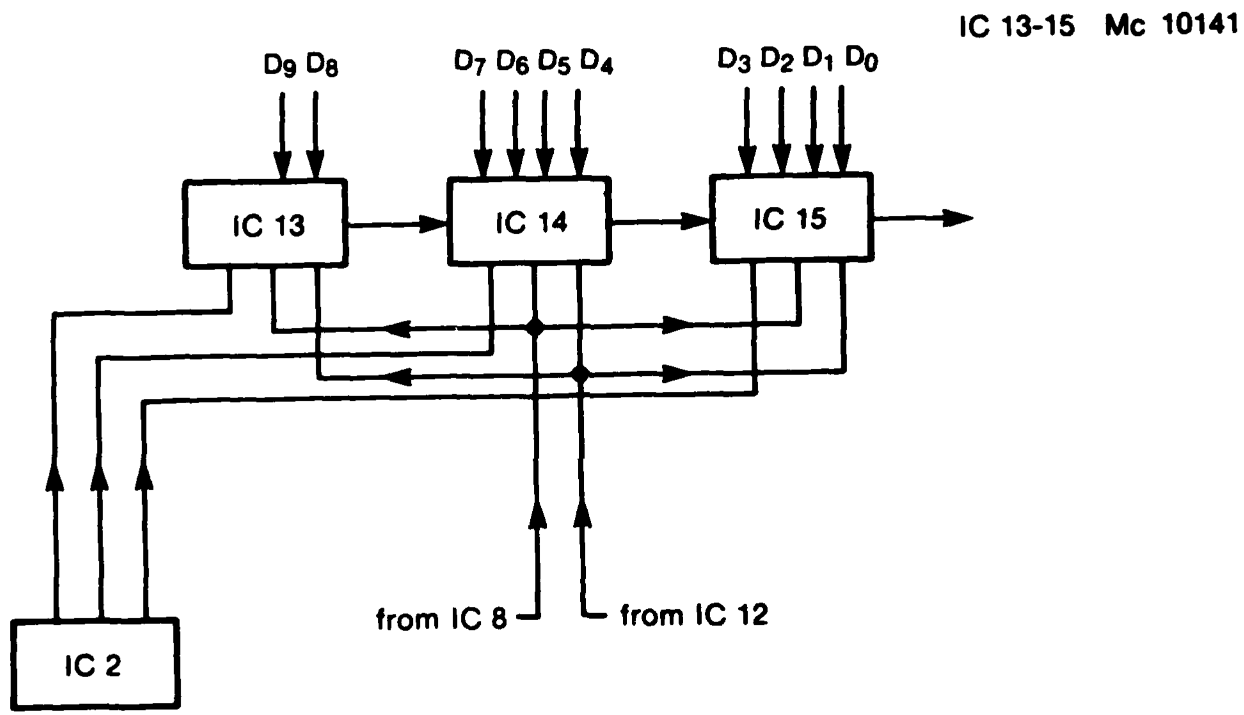


FIGURE 6 - SHIFT REGISTER CODING CIRCUIT

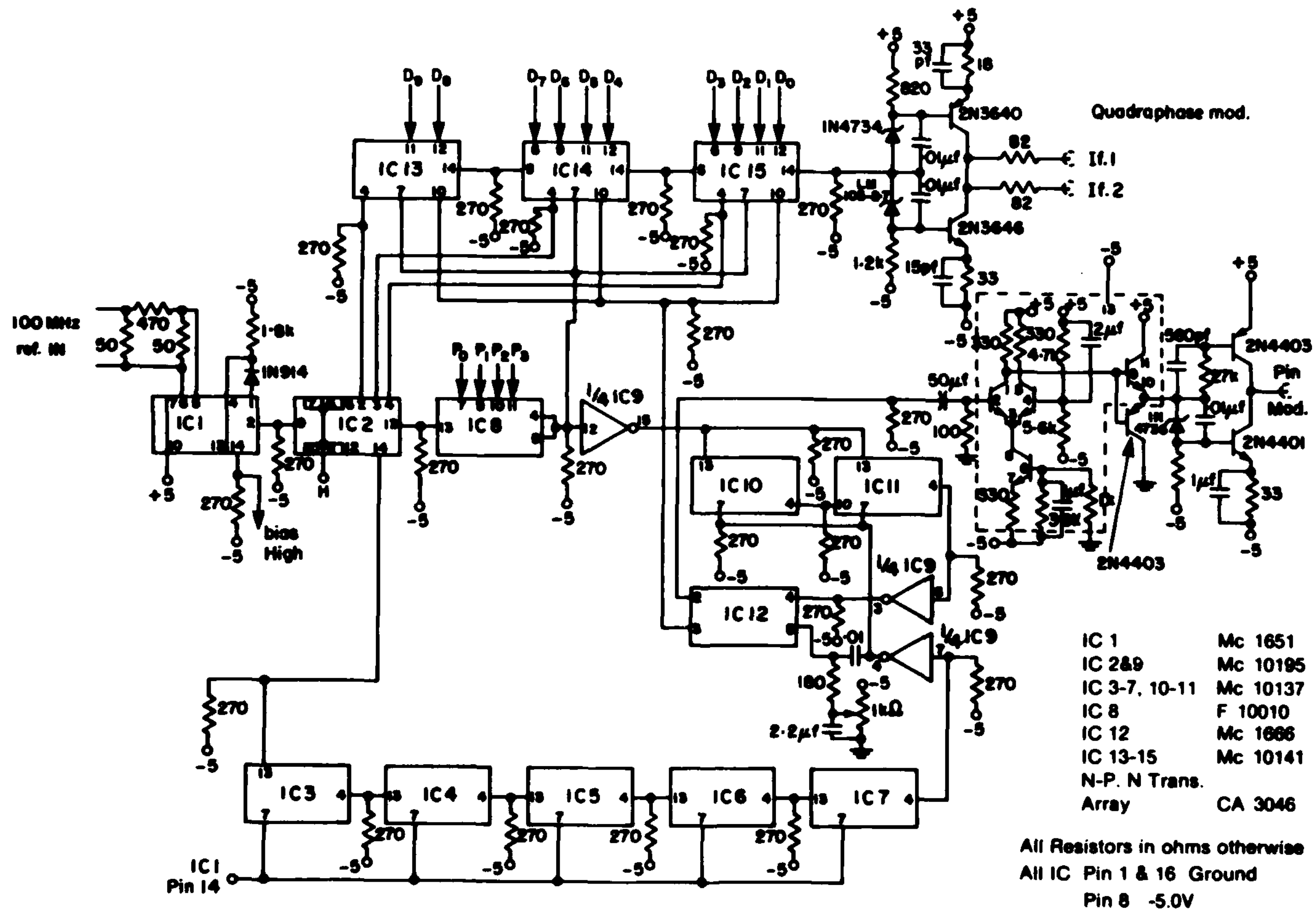
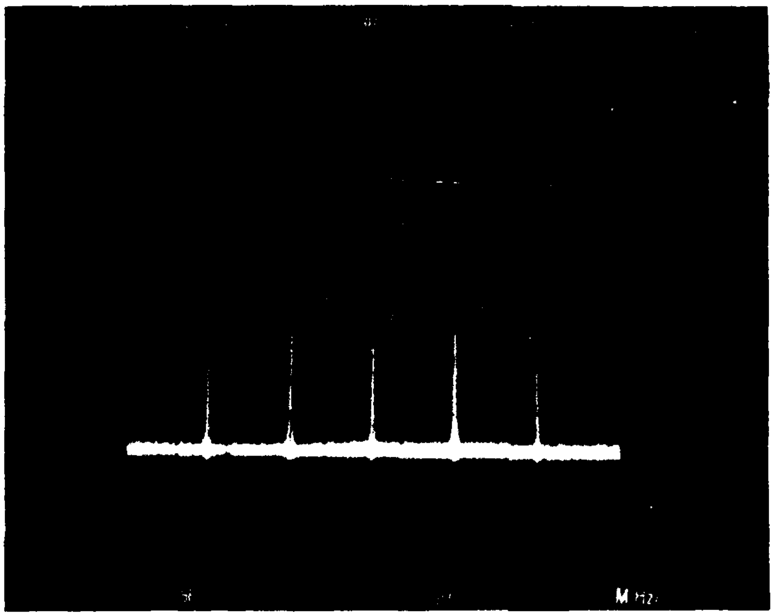


FIGURE 7 - MASTER SCHEMATIC OF ELECTRONIC SUBSYSTEM



f_c = 9.03[illegible] GHz
PRI = 1 ms
PW = [illegible] μs

FIGURE 8 - FREQUENCY SPECTRUM CODE SEQUENCE 010

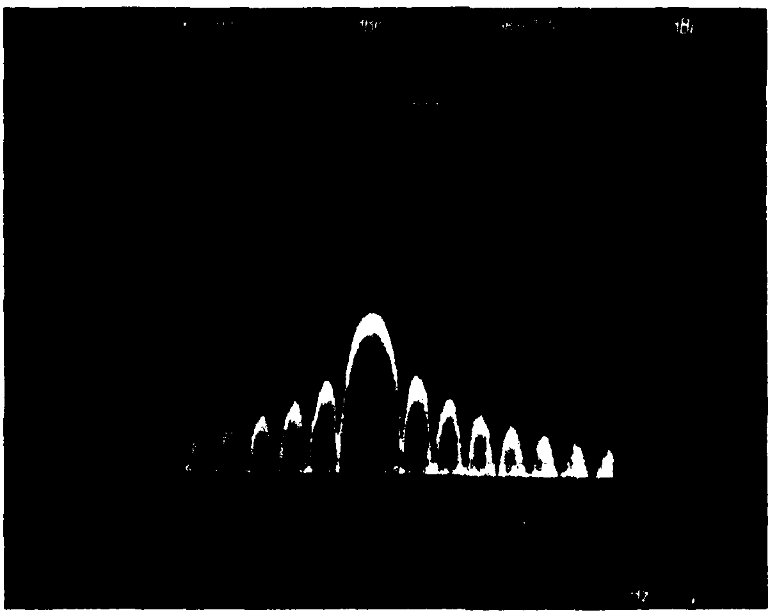
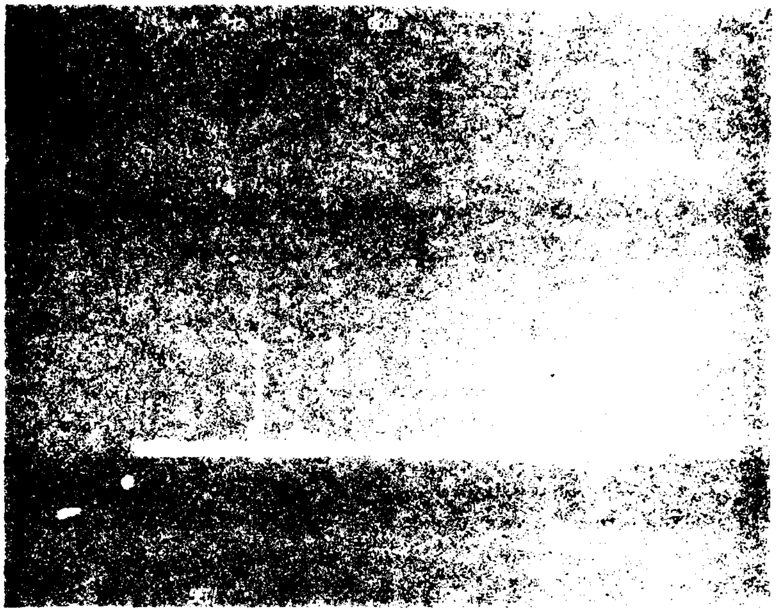


FIGURE 9 - SIN X/X FREQUENCY COMPONENT SPECTRUM

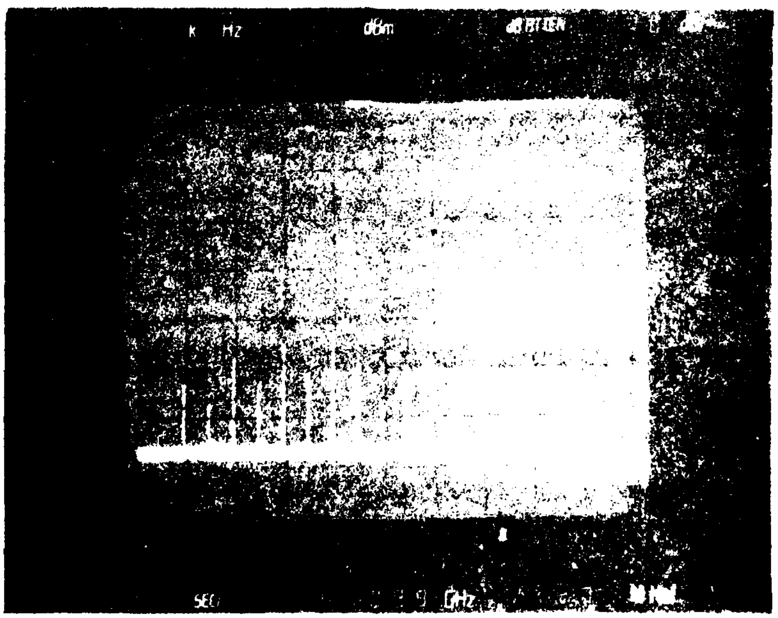


f_o = [illegible]

PRI = 1 ms

PW = 4 μs

FIGURE 10 – [illegible]



f_o = [illegible]

PRI = 1 ms

PW = 10 μs

FIGURE 11 – [illegible]

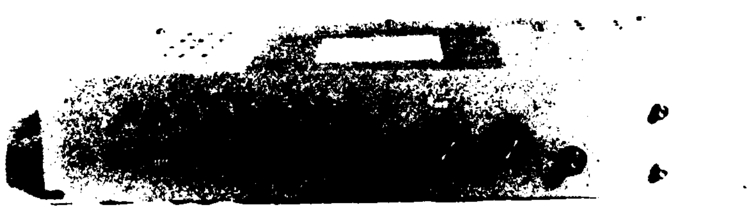


FIGURE 12 - BI-PHASE CODED RADAR SIGNAL SIMULATOR

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